7-26-2012 12:00 AM

Rule-Based Category Learning in Children: The Role of Inhibitory Control

Rahel R. Rabi
The University of Western Ontario

Supervisor
Dr. John Paul Minda
The University of Western Ontario

Graduate Program in Psychology
A thesis submitted in partial fulfillment of the requirements for the degree in Master of Science

Rule-Based Category Learning in Children: The Role of Inhibitory Control

(Spine title: Category Learning and Inhibitory Control)

(Thesis format: Monograph)

by

Rahel R. Rabi

Graduate Program in Psychology

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

The School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada

THE UNIVERSITY OF WESTERN ONTARIO
SCHOOL OF GRADUATE AND POSTDOCTORAL STUDIES

CERTIFICATE OF EXAMINATION

Supervisor	Examiners
Dr. J. P. Minda	Dr. L. Archibald
Supervisory Committee	Dr. J. B. Morton
Dr. L. Archibald	Dr. J. Sutton

The thesis by

Rahel R. Rabi

entitled:

Rule-Based Category Learning in Children: The Role of Inhibitory Control

is accepted in partial fulfillment of the
requirements for the degree of

Master of Science

Date________________________ ____________________________________
Chair of the Thesis Examination Board

Abstract

The present study examined category learning in relation to inhibitory control and working memory in children and adults. Results revealed that categorization performance improved with age. Young children struggled with rule learning, many older children were successful at rule learning, and most adults had no difficulty with the task. Model-based analyses suggested that performance differences were due to young children's inability to inhibit the salient, but irrelevant rule. Interestingly, when the analyses focused only on older children and adults who used the task appropriate strategy, the age-related rule-based deficit disappeared. Also, results revealed that successful performance on the categorization task was associated with better inhibitory control for older children, whereas successful performance on the categorization task was associated with greater working memory in young children. These findings suggest that the ability to learn categories varies with age and it may be partially dependent on inhibitory control and working memory.

Key words: category learning, rules, inhibitory control, working memory, development

Acknowledgments

I would like to thank my supervisor, Paul Minda, for his guidance throughout the development, research, and writing stages of my thesis. Also, thank you to my lab mates Sarah Miles and Ruby Nadler for their encouragement and comments throughout the duration of my project. Thank you to Sally Ao and Monica DaSilva for your time spent testing participants. I would also like to thank my supervisory and examining committee, Dr. Lisa Archibald, Dr. J. Bruce Morton, Dr. Jennifer Sutton and Dr. Daniel Ansari, for their participation and thoughtful feedback. Finally, thank you to my family and friends for their encouragement and support.

Table of Contents

Certificate of Examination ………………………………………………... ii

Abstract ……………………………………………………………… iii

Acknowledgments ………………………………………………………… iv

List of Tables ……………………………………………………….. vii

List of Figures ……………………………………………………….. viii

List of Appendices ……………………………………………………… ix

Introduction ………………………………………………………........... 1

Category Learning in Childhood …………………………………... 3

Inhibitory Control and Rule-Based Category Learning ……………. 7

The Role of Working Memory ……………………………………... 13

The Current Study ……………………………………………….. 14

Methods …………………………………………………………………. 17

Results …………………………………………………………………… 29

Discussion ……………………………………………………………... 43

Rule-Based Category Learning ……...…… 44

Category Learning and Inhibitory Control …………………………. 48

Neural Mechanisms Involved in Inhibitory Control ……………….. 51

Subtypes of Inhibitory Control …………………………………….. 52

Sources of Variability across Tasks ………………………………… 54

Category Learning and Working Memory …………………………. 56

Limitations and Future Directions ……………………………...….. 56

Conclusions …………………………………………………………….... 58

References ………………………………………………………………. 61

Curriculum Vitae ………………………………………………………….. 71

List of Tables

1 Description of Participants …………………………………………… 18

2 Distribution Parameters for the Rule-based Category Set ……......... 20

3 Average AIC values for participants best fit by either the frequency model or the orientation model ……………………………………… 37

4 Correlations between average categorization performance and executive functioning measures for younger children, older children, and adults ………………………………………………………. 38

List of Figures

1 Category structure for a rule-based category. Each light circle represents a stimulus from Category 1 and each dark circle represents a stimulus from Category 2 ………………………………………………………… 18

2 Three types of trials in the Flanker task ……..................................... 22

3 Go No-Go task sample trial set ………………………………………. 23

4 Sample congruent and incongruent trial from the Simon task (van den Wildenberg, Wylie, Forstmann, Burle, Hasbroucq, & Ridderinkhof, 2010) ……………………………………………………………………. 25

5 A sample trial from the rule-based categorization task ………………. 27

6 Individual learning curves, by age group. Each curve represents a single participant's performance ……………………………………... 30

7 Category learning performance for children and adults across 80 trials. Error bars denote standard error of the mean …………………………. 32

8 Category learning performance of older children and adults who performed within the top 20% of their age group (*n* = 12 older children; *n* = 12 adults). Error bars denote standard error of the mean .. 34

9 Proportion of participants who were fit by the optimal frequency model ……………………………………………………………….. 36

10 Correlation between categorization performance and flanker scores ….. 40

11 The correlation between flanker scores and AIC fit to the frequency model in older children ………………………………………………… 41

List of Appendices

Appendix A. Ethics Approval 70

Introduction

Categorization serves as the basis for the construction of our knowledge of the world. This fundamental decision-making process allows us to meaningfully parse the world, and to group like objects together so that they can later be treated as equivalent. Categories can be learned in many ways, which include adopting an overall-similarity approach to categorization or by using a rule-based approach to categorization (Bruner, Goodnow, & Austin, 1956; Ashby, Alfonso-Reese, Turken, & Waldron, 1998). Individuals have the ability to spread attention broadly over numerous stimulus dimensions, and to integrate two or more aspects of a stimulus to categorize objects. This overall-similarity approach to categorization is often referred to as family-resemblance categorization because members of a category family share similar features (Couchman, Coutinho, & Smith, 2010). Individuals also have the ability to focus attention toward a single stimulus dimension and use a single dimensional rule to categorize objects. This rule-based approach to categorization is particularly interesting to study because in many cases, the information needed for making a classification is encapsulated in a rule. For instance, when categorizing shapes, a child could apply the rule that shapes with three sides belong in the triangle category and shapes with four sides belong in the rectangle category.

Category learning involving both natural and artificial categories has been studied in infants (Quinn, Palmer, & Slater, 1999), children (Hayes, Foster, & Gadd, 2003; Sloutsky & Fisher, 2004), and adults (Minda & Smith, 2001;

Murphy, 2002). Artificially constructed categories are particularly useful to study because the structure of the category can be controlled and it can be assumed that participants have no prior knowledge about the category items. For example, consider an artificially constructed rule-based category set which varies along two dimensions: line orientation and spatial frequency. These categories could be mastered by using hypothesis testing to identify a verbalizable rule (e.g., “category 1 items have three or fewer stripes”). Even though this classification strategy appears simple, it requires sufficient cognitive resources (i.e., working memory, hypothesis testing, inhibitory control) to search for, store, and apply a rule, while inhibiting incorrect rules.

When learning rule-based categories, there are several key reasons to suspect that children and adults will exhibit differences in performance. First, compared to adults, children have a reduced working memory capacity (Gathercole, 1999). This finding implies that in situations where category learning relies on working memory (i.e., maintaining rules that have been tested in memory), children would not be expected to perform at the same level as adults. Second, relative to adults, children have a reduced capacity for hypothesis testing and rule selection (Bunge & Zelazo, 2006; Zelazo, Frye, & Rapus, 1996). This means that when category learning depends on testing and selecting rules, adults should outperform children. Lastly, compared to adults, children have reduced inhibitory control capacities (Dowsett & Livesey, 2000; Carver, Livesey & Charles, 2001; Dempster, 1992). This implies that when category learning involves inhibiting responses to a salient, but incorrect rule, adults should outperform children.

Rule-based category learning relies on processes thought to be mediated by the prefrontal cortex, which is a structure that develops later than other areas (Bunge & Zelazo, 2006). Support for the role of the prefrontal cortex in rule-based learning comes from research investigating patients with lesions of the prefrontal cortex. Knowlton, Mangels, and Squire (1996) showed that patients with prefrontal lesions were impaired in rule-based tasks but not in non-rule-based tasks involving overall similarity (Knowlton, Mangels, & Squire, 1996). Furthermore, verbal working memory and executive functioning develop substantially during childhood and are related to these physical developments in the prefrontal cortex (Gathercole, 1999). Since the prefrontal cortex is assumed to mediate rule-based learning, children should have difficulty relative to adults when learning these types of categories.

Category Learning in Childhood

To further explore these developmental differences in category learning, Minda, Desroches, and Church (2008) compared categorization performance in 3, 5, and 8-year-olds, as well as adults. Results revealed that adults outperformed children on categories that were optimally learned by a complex, disjunctive rule but that children and adults performed the same on an overall-similarity based categorization task. However, it was also found that children as young as 3 were able to learn simple, single-dimensional rules about as well as adults. This finding suggests that children were capable of learning these rules because they were easy to identify and they were directly related to perceptual experience. Given a more complicated case where a sub-optimal rule is associated with a salient feature, it is expected that children should follow the imperfect, salient rule and fail to perform at the same level as adults.

Minda and colleagues (2008) showed that children learned disjunctive, complex rule-based categories less well than adults. However, the task involved a category set for which only one strategy was viable. That is, only a disjunctive rule worked: single-dimensional rules or overall similarity type strategies produced chance performance on this category set. But, what about a case involving categories for which both rule-based and overall-similarity strategies might be available? Minda, Miles, and Rabi (submitted) examined this case by conducting two experiments wherein participants were given a five-dimensional category set that could either be learned perfectly by finding a single-dimensional rule or it could be learned perfectly by attending to the overall similarity of the category set. Alternatively, participants could attempt to solve the task by relying on a suboptimal rule.

In Experiment 1, children completed the categorization task, followed by a transfer stage where subjects classified new stimuli for which the rule information conflicted with the family-resemblance information. The transfer stimuli were used in order to identify the types of strategies children were adopting. Results revealed that adults tended to find and use the correct rule, while children were significantly less likely to classify the stimuli according to the correct rule. In addition, findings showed that children could find and use the correct rule when it corresponded to a perceptually salient feature. This suggests that children can find and use single feature rules when those rules correspond to dimensions which most capture attention. However, if the rule requires some degree of testing and inhibition to identify, children will have a difficult time finding it and rely instead on an imperfect rule and/or overall similarity.

In Experiment 2, Minda and colleagues tested participants on a set of stimuli with features that were of equal salience. A transfer phase was also included, as well as a single-feature phase in which subjects indicated in which category isolated features of a stimulus most often occurred. The single feature phase was used to determine whether subjects tended to focus on a single dimensional rule or overall similarity when categorizing. Subjects who focused on a single feature throughout the task should have difficulty categorizing many of the other features. However, individuals that used an overall similarity strategy in which they focused on multiple features should have been able to categorize more of the features. Findings once again showed that in the transfer phase, adults tended to make more classifications based on the correct single-dimensional rule than did children. With regards to the single feature phase, adults showed much better performance than children. Adults who were classified as using an overall similarity strategy performed the best and adults who were classified as identifying the correct single-dimensional rule also performed well on the single feature task. Thus, it appears that adults who adopted a rule-based strategy were also able to encode category knowledge regarding the other stimulus features. Overall, both experiments revealed that children are not as effective as adults at searching for and applying a categorization rule because they lack the necessary resources to fully engage in rule-based category learning.

Recent work by Huang-Pollock and colleagues (2011) has also examined developmental differences in the acquisition of category knowledge. Typically developing children between the ages of 8 and 13, as well as adults, learned several different category sets, including some that were rule-based and others that were based on overall similarity. In the rule-based tasks, adults outperformed children because children persistently used the irrelevant dimension to make their category judgments, whereas adults were able to inhibit that dimension to their benefit. In overall similarity task, adults outperformed children due to children's inability to shift from using a rule-based approach to an overall similarity approach. The fact that children persisted to use the irrelevant dimension as an imperfect rule implies that children seem to lack the inhibitory control and working memory ability necessary to engage in the hypothesis testing needed to find and use the optimal rule.

Inhibitory Control and Rule-Based Category Learning

To more fully understand category learning in children, it is necessary to understand the contributing strategies and processes (i.e., inhibitory control and working memory) that underlie performance. Huang-Pollock and colleagues (2011) hinted at the role of inhibitory control in rule-based category learning, but they did not actually measure inhibitory capacities in children. Results from the study revealed that, on average, accuracy rates were higher for adults than children on the rule-based categorization task. The reason being that children used the irrelevant dimension to guide categorization judgments more frequently than adults. However, a closer look at the individual performance profiles of the school-aged children might reveal some interesting differences. Even though, on average, adults outperformed children on the categorization task, individual learning data might reveal that some children performed quite well and displayed little to no performance deficit relative to adults. If this is the case, one might ask: what separates strong rule-based learners from weaker rule-based learners? If rule-based category learning involves some aspect of cognitive control, it is possible that an explanation for why some children perform better than others is because of enhanced inhibitory capacities relative to their peers.

Inhibitory control is a key process involved in executive functioning and it refers to the ability to suppress inappropriate responses in order to act appropriately (Nigg, 2000; Carlson, Moses, Hix, 1998). This cognitive process can further be broken down into two subtypes, which can be measured using different tasks. *Response suppression* refers to the ability to prevent or suppress an automatic or dominant response (Nigg, 2006). A specific task that has been used to index response suppression is the Go/No-Go task which requires a child to press a key ("go") when a frequent stimulus appears but to make no response ("no-go") when an infrequent stimulus appears. *Interference control* refers to the ability to filter out competing information that is irrelevant to the task being performed (Nigg, 2000). The Eriksen flanker task (Eriksen & Schultz, 1979), Simon task (Simon & Rudell, 1967), and Stroop task (Stroop, 1935) are common tasks used to measure interference control. In these tasks, the participant is presented with a stimulus that simultaneously activates two conflicting response channels; one response is activated by the instructions, whereas the other response is activated by elements in the array that invite the alternative, yet incorrect, response. In the Flanker task, participants respond to the direction of the middle target arrow while ignoring flanking arrows that point in the opposite or same direction as the target arrow. In the Simon task, participants give a left-right response to a non-spatial stimulus attribute (i.e., colour). Lastly, in the Stroop task, participants must resolve the conflict involved when the name of a colour (e.g., "blue", "red") is printed in a colour not denoted by the name. As a whole, the cognitive mechanisms involved in inhibitory control appear to be closely linked with rule-based category tasks, because successful performance on such tasks requires the ability to inhibit responding to a salient, but incorrect rule. Given the important role that inhibitory control appears to have in category learning, more research is required to understand the connection between these cognitive processes.

The connection between inhibitory control and rule-based category learning has been examined in older adults. Maddox, Pacheco, Reeves, Zhu, and Schnyer (2010) compared the performance of older and younger adults on a rule-based categorization task. Since frontal and striatal brain regions atrophy with normal aging (Grieve, Williams, Paul, Clark, & Gordon, 2007; Raz, 2000), it makes sense that age related declines would be observed in rule-based category learning. This would be especially true in cases where the categorization task places high demands on cognitive control mechanisms (Ridderinkhof, Span, & van der Molen, 2002; Filoteo, Maddox, Ing, et al., 2005). Results revealed that older adults were less accurate than younger adults on the categorization task and crucially, older adults were more likely to guess or switch strategies frequently, often failing to identify the correct rule.

In addition, inhibitory control (measured using the Stroop interference task and the Wisconsin Card Sort task) was correlated with performance on the rule-based task. More specifically, participants who performed well on the categorization task were also those who showed less interference and inhibition on the Stroop and Wisconsin Card Sort task. Furthermore, it was argued that inhibitory control tasks tap cognitive processes that are important for shifting strategies (i.e., shifting from one verbal rule to another). Interestingly, the rule-based deficit disappeared when Maddox et al. (2010) focused exclusively on older and younger adults who performed well on the categorization task. Therefore, older adults could perform at a similar level to younger adults if they possessed a sufficient level of inhibitory control needed to solve the rule-based task. It is possible that a similar relationship might also exist when comparing rule-based performance in middle-school children to adults. By the middle school years, children's inhibitory control capacity and overall executive functioning have matured quite a bit compared to younger children (Carver, Livesey, and Charles, 2001). Furthermore, it is plausible that middle-school children who are able to learn the correct rule and perform at a similar level to adults on a categorization task, might also display similar levels of inhibitory control as adult participants.

Additional research on rule-based category learning in normal aging has examined age-related changes in categorization performance across tasks that vary in rule complexity (Racine, Barch, Braver, & Noelle, 2006). Findings showed no performance deficit for older adults when the rule was simple, but found a large performance deficit when the rule was complex. The reason being that the demand for inhibitory control increased with rule complexity and this was associated with an age-related deficit. Racine and colleague's findings (2006) converge nicely with Minda et al. (2008) who found that children could learn a simple, single-dimensional rule, but struggled relative to adults when learning categories that were optimally learned by a more complex, disjunctive rule. Although Minda and colleagues (2008) did not test children's inhibitory control capacity, the findings of Racine et al. (2006) shed light on the fact that difficult, rule-based tasks place a greater demand on inhibitory control. It is likely that performance of children on the rule-based tasks might mirror that of older adults on similar types of tasks. Thus, this might be taken to mean that children with reduced inhibitory control abilities should perform less well on difficult, rule-based tasks compared to adults. However, in order to draw such conclusions more research is needed on the topic. For this reason, the current study will investigate the developmental role of inhibitory control in rule-based category learning.

It is important to study the status of rule-based categorization and its ties to inhibitory control in children because it is during childhood that executive processes such as working memory and inhibitory control are continuing to develop (Dowsett & Livesey, 2000). According to Zelazo and Frye's Cognitive Complexity and Control (CCC) Theory, age-related changes in the control of behaviour are explained by the acquisition of increasingly complex rule systems (Zelazo & Frye, 1998). The increase in complexity allows children to use a higher order rule to decide, for example, which of two incompatible pairs of rules to use.

One of the tasks that has been used to study children's ability to reflect on rules is the card sort task, which places two different pairs of rules in conflict with one another. Children are shown a set of cards with two dimensions (e.g., colour and shape) and are given rules for sorting on one dimension. After a set number of trials, children are asked to sort on a different dimension. When asked to complete the card sort task, young children are able to use the first rule to sort the cards successfully; however, when asked to switch rules, they perseverate to the first rules learned (Zelazo, Frye, & Rapus, 1996). The CCC theory attributes this failure to switch rules to a lack of reflection on rules. Although young children can consciously represent the relevant rules, they fail to utilize them because they cannot form a clear, higher order rule. As well, CCC theory explains that the inability to shift between an incompatible pair of rules may reflect the immaturity of the neural mechanism responsible for response inhibition.

Additional support for developmental differences in inhibitory control comes from research by Carver, Livesey, and Charles (2001). Children ages 5 to 9 were presented with a stop-signal task (i.e., task used to measure the ability to withhold inappropriate responding to a stimulus) to perform. Findings showed that the ability to withhold a response improved with age. That is, older children were more likely to inhibit a response than younger children because their inhibitory processes act more efficiently. Therefore, developmental constraints prevent children from properly inhibiting responses on inhibitory control tasks and it seems as though this constraint should also impact performance on rule-based categorization tasks.

The Role of Working Memory

In addition to inhibitory control, rule-based category learning also appears to be influenced by working memory. Lewandowsky (2011) examined the relationship between working memory and category learning in adults. Results indicated that working memory capacity mediated performance on rule-based tasks. DeCaro, Thomas, and Beilock (2008), have also shown that individuals with low working memory capacity are slower at learning rule-based categories than individuals with high working memory capacity. As well, neuropsychological research has revealed that working memory and rule implementation rely on overlapping dorsal lateral prefrontal regions (Stuss & Knight, 2002). Given the fact that working memory capacity is still developing throughout childhood, it is likely that children should take longer to learn rule-based categorization tasks in comparison to adults.

Research has also been done examining the link between working memory and inhibitory control. Espy and Bull (2005) investigated inhibitory control performance differences in children (ages 3-6) with high and low digit span scores (i.e., a measure of working memory). Performance on inhibitory control tasks that require cognitive engagement/disengagement among an internally represented rule differed between children of high and low working memory. It appears that children with lower memory spans have difficulty controlling attention and are less able to inhibit a rule that has been previously active. This difficulty interferes with the child's ability to implement a new rule.

Therefore, it seems as though a link exists between working memory and inhibitory control, where if an individual is not able to maintain information over time and/or inhibit responses, that individual may struggle with identifying the correct rule. In comparison, individuals with efficient inhibition skills should perform well on rule-based tasks because they are able to keep out irrelevant information from working memory. Altogether, it appears that to succeed at rule-based categorization one needs to have sufficient working memory capacity and inhibitory control.

The Current Study

Although there has been research implicating the role of maturation in improving executive functioning, there has yet to be research investigating the direct effect of inhibitory control on categorization performance in children. The current study was designed to examine differences between children's and adults' category learning abilities and styles and how these differences relate to inhibitory control. Participants (ages 4-7 years, 8-11 years, and adults) were first asked to complete a rule-based categorization task, which required them to identify a single-dimensional rule. In order to correctly classify the stimuli, the learner must base their response on one dimension while ignoring the other. However, finding and using the rule requires verbal working memory to state the rule, hypothesis testing to search for the rule (based on two visually similar dimensions) and also inhibitory control to inhibit responding to the salient, but incorrect rule.

It is assumed that adults have a fully-developed executive functioning system, and so should be successful at finding and using the correct rule to classify the stimuli. In contrast, children's executive functioning abilities are still developing, and as a result they should be less effective at finding and using the correct rule and instead allow the irrelevant dimension to guide behaviour. These predictions are in line with Huang-Pollock et al. (2011) and Minda et al. (submitted) who both found that children are simply not as effective as adults at searching for and applying a categorization rule. Children, unlike adults, have difficulty relying on the executive functioning system because the prefrontal cortex has not sufficiently developed to allow for its full operation (Bunge & Zelazo, 2006). Therefore, it was predicted that children can learn a single-feature rule but they would have difficulty switching to another rule if the one they initially used was incorrect. With regards to the two different age groups of children, it was hypothesized that older children (ages 8-11) would perform better than the younger children (ages 4-7) but would still not be able to perform at the same level as adults. This is thought to be the case because although 8 to 11 year olds should show improvements in executive functioning (i.e., hypothesis testing, inhibitory control, and working memory), it is not until late in adolescence that the prefrontal cortex fully develops (Bunge & Zelazo, 2006).

Following the rule-based categorization task, participants completed three inhibitory control tasks which measured response suppression (i.e., Go/No-Go task) and interference control (i.e., Flanker and Simon task). It was predicted that inhibitory control would correlate highly with rule-based categorization performance. These predictions are in line with Maddox et al. (2010) who showed that inhibitory control was correlated with performance on rule-based tasks in older adults. This finding suggests that the cognitive processes associated with inhibition of non-dominant rules, as measured by the inhibitory control tasks, are relevant to rule-based learning and that these abilities are predictive of who will ultimately learn to utilize the task appropriate strategy.

Rule-based learning also relies on working memory to test and store hypotheses and rules, and so working memory capacity will also be measured in this experiment. Participants were given a digit span task to complete where they had to repeat a list of numbers in the correct order. Waldron and Ashby (2001) have shown that working memory plays a large role in rule learning and is required to learn categories for which the optimal rule is verbalizable. Given this finding, it was predicted that adults would have a large working memory capacity and so would rely on verbal working memory to identify the correct rule in the categorization task. In comparison, children should have a smaller working memory capacity, and as a result of this should perform less well on the categorization task. Once again, it was predicted that older children would outperform younger children because their working memory abilities are more developed.

Methods

Participants

Table 1 provides a description of participants. A total of 42 typically developing 4 to 7-year-olds were recruited through local schools and child care centres. As well, 57 typically developing 8 to 11-year-olds were recruited from local schools. Children provided verbal assent and parents also provided written consent prior to participation. Children were given stickers for participating in the study. Fifty-six college-attending adults were recruited from the Department of Psychology research pool at the University of Western Ontario or through a paid advertisement. Adult were given course credit or $10 for their participation in the study[1].

Materials & Measures

Categorization Task. In the rule-based categorization task, participants classified sine-wave gratings that varied in spatial frequency and orientation. Figure 1 demonstrates a rule-based category where the vertical line separating Category 1 and Category 2, known as the decision bound, represents the strategy

---

[1]Categorization performance did not differ between participants who received course credit and those who were paid.

Table 1: Description of Participants

Category Structure	Gender Males: Females	Age (years) Mean (SD)
Young Children	27:15	6.10 (.68)
Old Children	35:22	9.48 (.88)
Adults	7:29	19.16 (1.64)

Note. Standard deviations are in parentheses. The group of young children included 1 four-year-old child, 17 five-year-old children, 19 six-year-old children, and 5 seven-year-old children. The group of older children included 20 eight-year-old children, 18 nine-year-old children, 16 ten-year-old children and 3 eleven-year-old children.

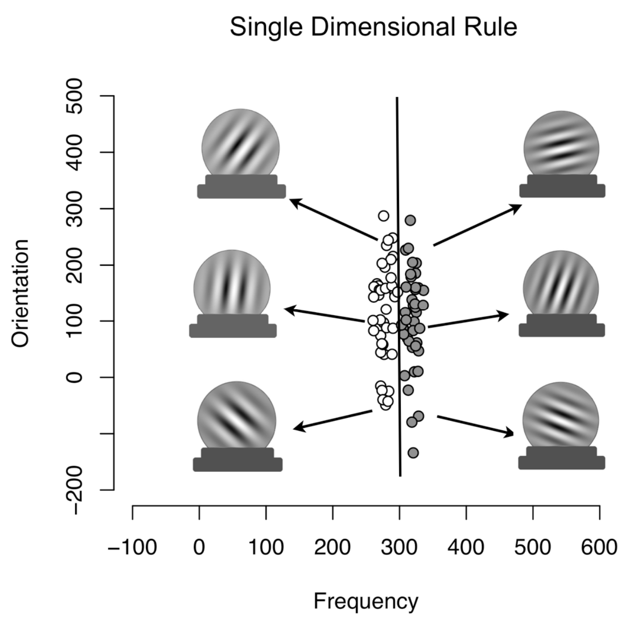

Figure 1. Category structure for a rule-based category. Each light circle represents a stimulus from Category 1 and each dark circle represents a stimulus from Category 2.

that maximizes categorization accuracy (Ashby & Gott, 1988). Points falling to the left of the decision bound are members of Category 1 and points to the right are members of Category 2. In order to correctly classify the stimuli in Figure 1, the learner must base responding on the frequency dimension while ignoring the more salient orientation dimension. The optimal verbal rule could be phrased as: "Crystal balls with few lines go in Category 1, crystal balls with many lines go in Category 2". Subjects completed a total of 80 trials.

Eighty stimuli were generated (Ashby & Gott, 1988; Zeithamova & Maddox, 2006), with 40 in Category 1 and 40 in Category 2. The distribution of each category was specified by a mean and variance for frequency and orientation, and covariance between them. For each category, 40 values were randomly sampled from a multivariate normal distribution described by the parameters for that category (Table 2).

The PsychoPy package (Pierce, 2007) was used to generate a sine wave grating (a Gabor patch) corresponding to each coordinate sampled from the distribution above. The sine wave grating frequency was calculated as $f = .25 + (\chi_f / 50)$ and orientation was calculated as $o = \chi_o \times (\pi / 500)$. Two solid bars were added to the bottom of each stimulus, so that that stimulus resembled a "crystal ball" which would then be classified as belonging to a certain wizard (category).

Table 2: Distribution Parameters for the Rule-Based Category Set

Category Structure	μ_f	μ_o	σ^2_f	σ^2_o	$cov_{f,o}$
Rule-Based					
Category 1	270	125	75	5000	0
Category 2	330	125	75	5000	0

Working Memory Tasks

Forward Digit Span. Participants heard a recording of a two-digit number sequence at a rate of approximately one digit per second, and the participant was asked to repeat the sequence back to the experimenter in the same order. The task began with four practice trials in which the participant responded and received feedback. Children heard three sequences at each sequence length and as long as they repeated at least one of them correctly they continued on to the next sequence length, for a maximum length of ten digits. The task was over once the participant was unable to repeat any of the sequences at a given length. No feedback was given throughout the task. The forward digit span score was calculated as the total number of correct responses given.

Backward Digit Span. The procedure for the backward digit span was the same as that for the forward digit span except that the participant was required to recall the digits in reverse order so that the last number was said first and the first number was said last, for a maximum of eight digits. The task was scored as the total number of correct responses.

Inhibitory Control Tasks

Flanker Task. A version of the Flanker task adapted from Botvinick, Nystrom, Fissel, Carter, and Cohen (1999) was used to measure interference control (i.e., a subtype of inhibitory control associated with the ability to filter out competing information). In this task, a set of five arrows were presented in a row on the computer screen and participants were asked to indicate the direction of the central arrow (target) that was pointing to the left or the right with a speeded keypress response (see Figure 2). Participants rested their index finger of each hand gently on each of the two keys. These keys were labeled with stickers displaying a picture of a left arrow and a right arrow to make it easy to explain the rules. The target was flanked by two identical arrows on either side (distractors) that were either pointing in the same direction (i.e., a congruent trial) or the opposite direction of the target arrow (i.e., an incongruent trial). On incongruent trials, the irrelevant, distracting information from the flanking arrows must be filtered out, a process thought to require inhibitory control (Botvinick et al., 1999). Neutral trials were also included where arrows surrounding the target arrow were replaced by squares. The task consisted of 60 trials (20 congruent, 20 incongruent, and 20 neutral) presented in randomized order. Each stimulus was presented for 4000 ms with an interstimulus interval of

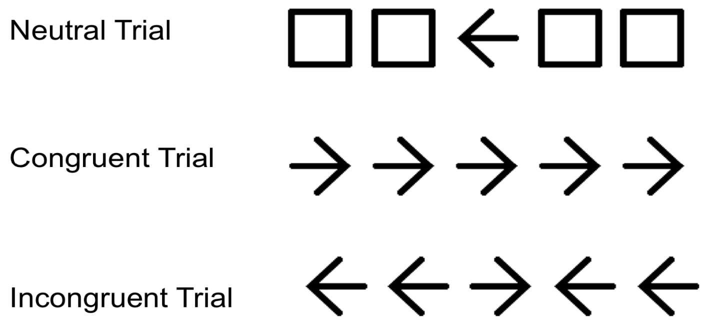

Figure 2. Three types of trials in the Flanker task.

1000 ms. Prior to the experiment participants received five practice trials that were not analyzed. The task lasted approximately five minutes.

Go/No-Go Task. The second inhibitory task presented was the Go/No-Go paradigm, used to measure response suppression (i.e., a subtype of inhibitory control associated with the ability to inhibit a prepotent response) (Berlin & Bohlin, 2002; Lindqvist & Thorell, 2009). The participant was presented with four different stimuli: a red square, a blue square, a red circle, and a blue circle. In the first block, the individual was instructed to press a button every time a square appeared on the computer screen, irrespective of its colour (i.e., go trial), but to make no response when a circle appeared (i.e., no-go trial) (See Figure 3). In the second block, the individual was instructed to press a button every time a blue figure appeared on the computer screen, but to make no response when a red figure appeared. A total of 60 stimuli were presented with 30 stimuli

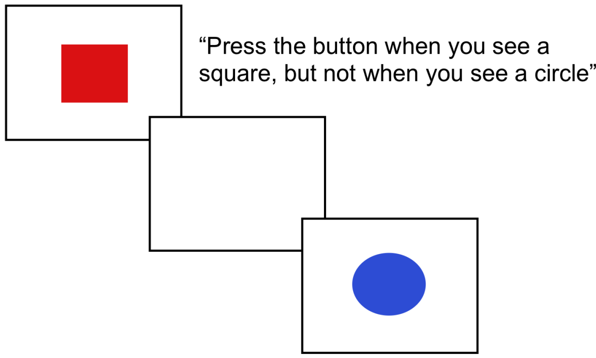

Figure 3. Go No-Go task sample trial set.

presented per block and the blocks were counterbalanced. The first block was used to develop a response habit (prepotent response) to the first rule. The second block examined the ability to respond as quickly as possible using a new rule while withholding a response to trials which satisfied the first rule, the previously learned behavior. Each figure was presented for 800 ms with an interstimulus interval of 2000 ms. Thirty percent of the trials were no-go trials (i.e., 18/60 trials). The task lasted approximately five minutes. This task was scored according to the number of commission errors (i.e., incorrectly responding to a no-go trial). Omission errors were not measured because they are thought to be fundamentally different in nature from commission errors, and are not considered to be an indicator of inhibitory control (Drew, 1975). In the Go/No-Go task, omission errors tap into attention/concentration factors rather than inhibition capacity.

Simon Task/Spatial Conflict Task. The third inhibitory task presented to participants was the Simon task which measures interference control (Simon & Rudell, 1967). Participants placed their index finger of each hand gently on each of the left and right shift keys (see Figure 4). These keys were labeled with white stickers displaying a red circle for the left shift key and a blue circle for the right shift key to make it easy to explain the rules. The experiment was built and run using the Psychology Experiment Building Language (PEBL) software (Mueller, 2010). Participants were first presented with a fixation cross in the center of the screen that remained visible for 400 ms. Immediately after the cross had disappeared a red or blue circle appeared at one of seven possible locations on the screen: far left, left, left-centered, the center, right-centered, right, or far right. Participants were instructed to press the left key in response to the red circle and the right key in response to a blue circle as fast as possible, regardless of stimulus location. The timing began with the onset of the stimulus, and the response terminated the stimulus. Participants received a total of 70 trials (35 red stimuli and 35 blue stimuli) in random order. Ten stimuli appeared in each of the seven possible stimulus locations, so there were 30 congruent trials, 30 incongruent trials, and 10 neutral trials (the stimulus appeared in the center of the screen). The trials on which the stimulus location was on the same side as the required response were the congruent trials and the trials on which the stimulus location was on the opposite side of the required response were the incongruent trials. Prior to the experiment participants received five practice

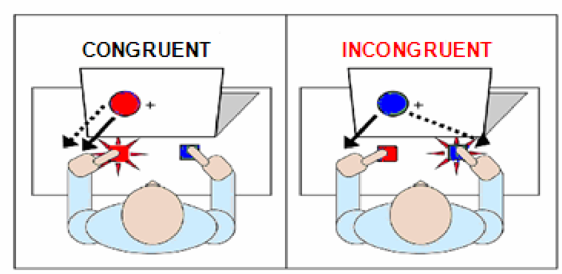

Figure 4. Sample congruent and incongruent trial from the Simon task (van den Wildenberg, Wylie, Forstmann, Burle, Hasbroucq, & Ridderinkhof, 2010).

trials that were not analyzed. Similar to the Flanker task, the amount of interference displayed by an individual was determined by their difference score (i.e., mean reaction time on congruent trials was subtracted from the mean reaction time on incongruent trials for correct trials only). The Simon task lasted approximately five minutes.

Procedure

Session 1: Category Learning & Working Memory Tasks. Children were tested individually in a room near their classroom. The child and the experimenter were seated at a table in front of a 13-inch Apple MacBook computer. During the first testing session, children were told that they would be playing a game in which they would see pictures of crystal balls on the computer screen and that some of the crystal balls belonged to a blue wizard and some belonged to a green wizard. Their job was to figure out which crystal balls belonged to the blue wizard and which belonged to the green wizard by clicking on the correct wizard on the screen (See Figure 5). On each trial, a picture of a crystal ball appeared in the middle of the screen and pictures of two “category labels” (blue or green wizard) were shown in the top left and right corners of the screen. The crystal ball remained on the screen throughout the entire trial until a response was made. The correct category label was circled after each response regardless of whether the response was correct or incorrect. As well, a row of ten small white progress circles were shown along the top of the screen. Each time a trial was completed, a checkmark or X appeared in a circle at the top of the screen, depending on whether the child made a correct or incorrect response. After ten trials, when all the circles were filled, the circles all became white and a new set of ten trials began. These circles acted as a tool for subjects to keep track of their progress throughout the experiment. Correct responses were indicated with a bell sound and a green check mark displayed in the center of the screen for three seconds and incorrect responses were indicated with a red X for three seconds and a buzz sound.

Following the rule-based categorization task, children received a short break, after which they were administered the digit span task. Each child’s working memory was measured using forward and backward digit span. For the forward digit span task, children would hear a recording of a number sequence and repeat the sequence back to the experimenter. The procedure was exactly

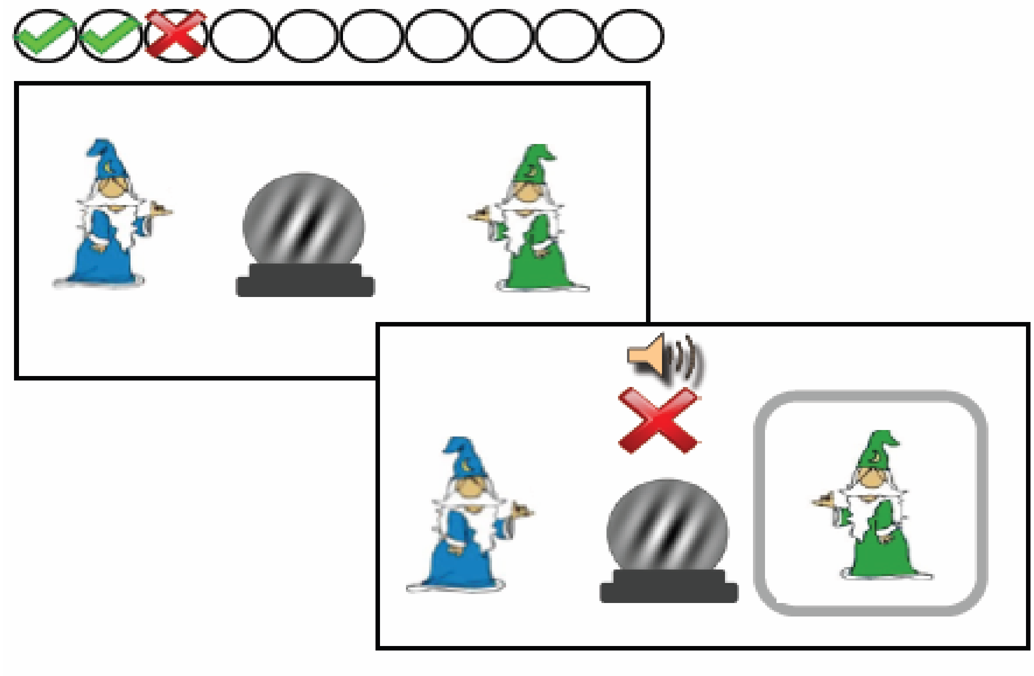

Figure 5. A sample trial from the rule-based categorization task.

the same for the backwards digit span, except that participants were now instructed to repeat the sequence back in reverse order. The first testing session lasted approximately half an hour.

Session 2: Inhibitory Control Tasks. Approximately 1-2 weeks after the categorization task and digit span tasks, each child's inhibitory control abilities were measured during a second testing session using three different computer tasks. First, participants completed the Flanker task on a 13 inch Apple MacBook computer. They were told that they would see an array of five arrows on the screen and their task was to press the arrow key on the keyboard that corresponded to center arrow in the array as quickly as possible. The center arrow was sometimes flanked by identical surrounding arrows (congruent trials), opposite surrounding arrows (incongruent trials), or squares (neutral trials). Response time and accuracy was measured.

The second task individuals completed was the Go-No/Go task. Participants were told that they would see a red circle, red square, blue circle, or blue square on the screen and their task was to press a button as quickly as they could every time a trial satisfied the rule given to them at the start of the task (e.g., press the button every time you see a square but not a circle). After 30 trials, a new instruction screen appeared describing a new rule to follow (e.g., "Now, press the button every time a blue shape appears but do not press the button when a red shape appears"). The instructions were read aloud to all children. Number of commission errors (making a response on a no-go trial) was measured.

The last inhibition task administered to individuals was the Simon task, which consisted of 70 trials. Participants were told that they would see a red circle or blue circle somewhere along the midline of the screen and their task was to press the "red circle key" every time they saw a red circle and the "blue circle key" every time they saw a blue circle as fast as they could. On half of the trials the stimulus location was on the same side as the required response (congruent trials) and on the other half of trials the stimulus location was on the opposite side of the required response (incongruent trials). Response time and accuracy was measured.

The three inhibitory control tasks were always administered in the same order to all of the participants. The second testing session lasted approximately 20 minutes and children were given short breaks between inhibition tasks.

Adults were tested individually using the same basic procedure as children except that adults were tested in a lab setting, whereas children were tested in a school setting (i.e., in an empty classroom). Adults completed each testing session on separate days, approximately 3-7 days apart. As well, adults read the instructions for each task on their own.

Results

Categorization Performance – Individual Data. Of the participants who completed the categorization task, three adults were excluded from the analysis (two adults displayed fast reaction times indicating that they were not actively trying to solve the task and one adult responded Category 1 to all trials). In order to demonstrate the range of performances that participants showed, individual learning data was examined. For each participant, categorization performance was determined for each set of 20 trials. Figure 6 illustrates individual learning curves for participants in each age group. First considering young children, categorization performance was uniformly quite low across trials (between 40-

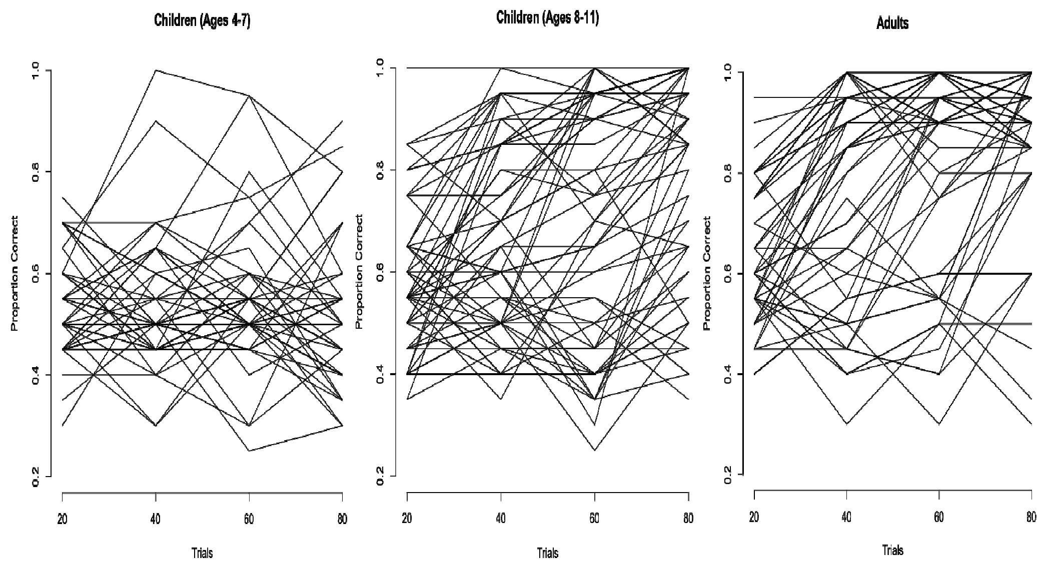

Figure 6. Individual learning curves, by age group. Each curve represents a single participant's performance.

60%), with the exception of a few young children who were able to identify the correct rule and solve the task. This result suggests that as a group, young children struggled with rule learning. In contrast, the categorization performance of the older children was much more variable. Performance was composed of a group of older children who appeared to have learned the categorization rule quickly (similar to adults), a group who showed delayed learning, and a group who showed no learning across the entire experiment. The majority of adults appeared to have learned the categorization rule quickly, with the exception of a handful of adults who showed no learning throughout the task.

Categorization Performance – Averaged Data. The learning rate of the rule-based categories was examined in the three groups of participants. For each group of children and adults, the average proportion correct for each block of 20 trials was calculated. The resulting learning curves are shown in Figure 7 and these data suggest that at the start, all age groups were performing at a similar level, but with practice adults and older children were clearly outperforming younger children. A 3 (age) x 4 (block) mixed ANOVA revealed a main effect for block, F (3, 44) = 34.34, p < .001, illustrating that learning occurred between the first and fourth blocks. As well, a main effect was also found for age, F (2, 149) = 32.58, p < .001, indicating that adults (M = .76, SD = .14) generally categorized better than younger children (M = .54, SD = .09) and older children (M = .68, SD = .16).

Of particular interest, an interaction was found between age and block, F (6,447) = 8.87, p = < .001, indicating that across the four blocks a difference emerged between the performance of young children, older children, and adults. Most notably, young children showed little evidence of learning, performing at just above chance across all trials. In contrast, with practice, older children and adults showed evidence of category learning. A Tukey's HSD test was conducted to further examine this interaction and revealed that adults (M = .87, SD = .17) significantly outperformed younger children (M = .53, SD = .15), q = 13.75, p = < .001, during the last session block. In addition, older children (M =.79, SD = .20) outperformed younger children, q = 10.58, p = < .001, by the

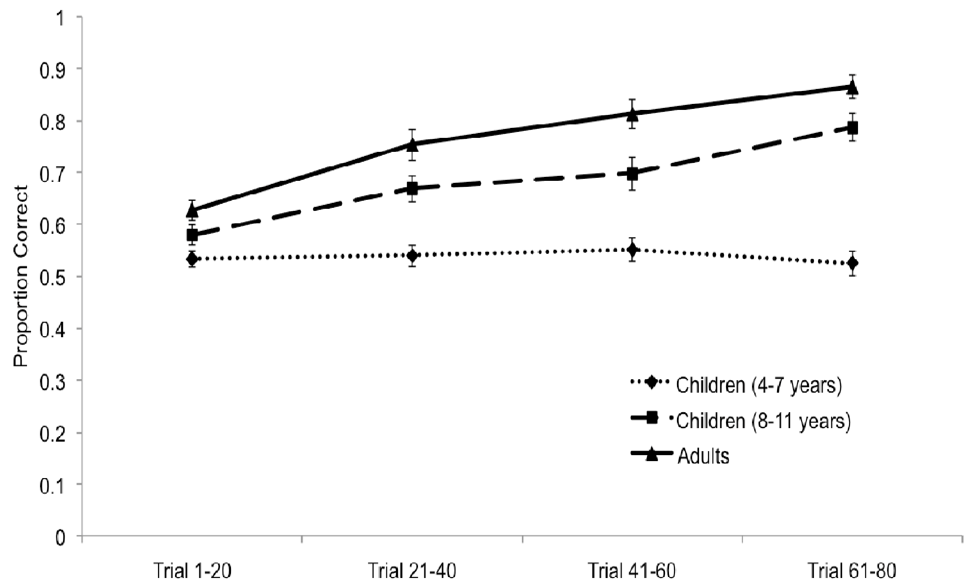

Figure 7. Category learning performance for children and adults across 80 trials. Error bars denote standard error of the mean.

last block. Interestingly, there was no significant difference between final block performance in older children and adults, $q = 3.16$, $p = .066$, indicating that given enough practice, older children can perform at the same level as adults.

High-Performing Rule Learners. The variation in the performance profiles of the older children warrants further investigation. Even though as a whole, adults average categorization performance was higher than older children, the individual learning curve data presented in Figure 6 highlights the fact that some older children can perform at the same level as adults. To further explore this finding, the average categorization performance of older children and adults who performed within the top 20% (n = 12) of their age group was compared. Figure 8 illustrates that for the first 40 trials, older children were performing at a similar level to adults, and both groups appeared to have learned the rule quickly. Interestingly, for the last 40 trials the categorization performance of older children and adults was nearly identical. A 2(age) x 4(block) mixed ANOVA revealed a main effect of block, F (3, 66) = 34.56, p < .001, indicating that learning occurred across trials, but no main effect of age, F (1,22) = 2.35, p = .14, and no interaction, F (3, 66) = 2.18, p = .10. This shows that across the four blocks there was no significant difference in categorization performance between top child category rule learners and top adult category learners.

The Relationship Between Age & Category Learning. Correlational analysis was conducted to determine whether a relationship exists between age in months and average categorization performance within each age group. Results revealed that within the group of younger children, age was positively correlated with overall categorization performance, r (40) = .42, p =.003. In contrast, there was no correlation between age and average categorization in older children, r (55) = .09, p = .25, and adults r (51) = - .11, p = .21, indicating that some other factor(s) are responsible for variation in categorization performance.

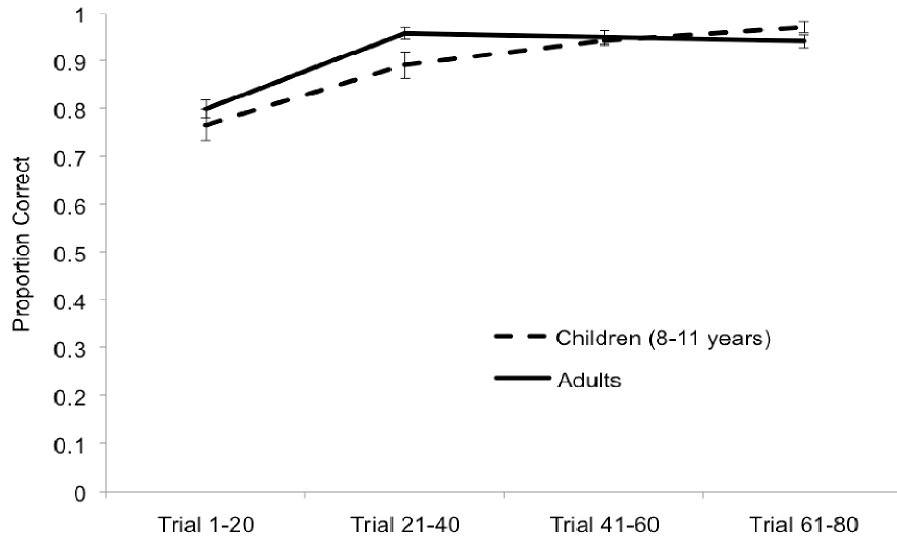

Figure 8. Category learning performance of older children and adults who performed within the top 20% of their age group (n = 12 older children; n = 12 adults). Error bars denote standard error of the mean.

Model-Based Analysis. For insight into the response strategies used by children and adults, decision bound models were fit to each participant's data (see Maddox & Ashby, 1993 for a detailed description of these models). Different models make different assumptions about the type of strategy that the participant is using. The models can be used to determine whether each participant is using the task appropriate strategy (i.e., basing responses on the frequency dimension) or a sub-optimal strategy to solve the task (i.e., basing responses on the orientation dimension, when frequency is the correct rule). Two different rule-based models were fit to each participant's responses across all 80 trials. The first is the unidimensional frequency model, which assumes a unidimensional rule along the frequency dimension while ignoring the orientation dimension (an optimal version with a fixed intercept was used). The second is the unidimensional orientation model, which assumes a unidimensional rule along the orientation dimension while ignoring the frequency dimension (a version with the intercept as a free parameter was used). Both of these models were fit to each participant's data by maximizing the log likelihood (Wickens, 1982). Model comparisons were based on the AIC (Akaike information criterion) statistic that penalized a model for each additional free parameter with AIC = (2 x n) + (2L), where n equals the number of parameters and L is the maximum likelihood estimated of the data given the model (Akaike, 1974).

The proportion of children and adults best fit by each model is shown in Figure 9. Among the group of younger children, 64.29% were best fit by the optimal frequency model. In comparison, the optimal frequency model best fit 91.23% of older children and 94.34% of adults. Model-based analyses suggest that the reason why younger children performed more poorly is because they tended to base their judgments along the irrelevant dimension (i.e., line orientation) more often than older children and adults. This finding was confirmed by numerous self-reports from young children indicating that they were using a strategy based on orientation. To further investigate strategy use among different age groups, average AIC values for children and adults best fit

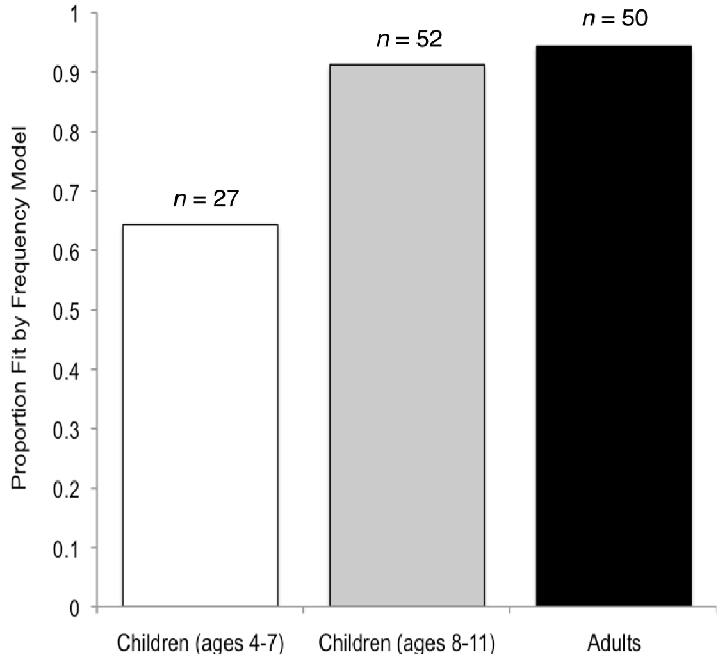

Figure 9. Proportion of participants who were fit by the optimal frequency model.

by either the frequency model or orientation model were examined (lower AIC values indicate a better fit). Table 3 illustrates that adults were best fit by the frequency model (*AIC* = 77.93), while younger children displayed the poorest fit to the frequency model (*AIC* = 109.12), and older children fell somewhere in between (*AIC* = 89.78). The fact that younger children had the poorest fit to the frequency model indicates that instead of using frequency as their rule to solve the categorization task, some of the children best fit by the frequency model may have actually been using some other type of strategy (i.e., guessing or a mixture of frequency and orientation rule-use).

Table 3: Average AIC values for participants best fit by either the frequency model or the orientation model.

Best Fit	Children (ages 4-7)	Children (ages 8-11)	Adults
Frequency Model	109.12	89.78	77.93
Orientation Model	109.21	110.56	101.14

Note. The lower the AIC value, the better the fit.

Inhibitory Control. Correlations between inhibition capacity measures and average categorization performance were computed to establish whether a relationship exists between inhibitory control and rule-based category learning (see Table 4)[2]. In the Flanker and Simon task the difference in mean reaction time between correct responses on congruent and incongruent trials (i.e., a difference score) was used as a measure of interference control. Only correct responses to Flanker and Simon trials were used in the analysis because when measuring inhibitory control, one is interested in measuring the ability to properly inhibit a response. Larger difference scores were indicative of less efficient interference control. The general finding being that reaction times are longer on incongruent trials because of the additional attentional processing

[2]Scores on the three inhibition tasks were not collected for 2 young children and 3 adults because they were absent during the second testing session. In addition, in the Flanker and Simon task, outlier reaction time scores were removed (i.e., scores greater than 2 standard deviations above the mean). This resulted in less than 3% of all trials being removed.

Table 4: Correlations between average categorization performance and executive functioning measures for younger children, older children, and adults.

Average Categorization Performance			
Measure	Children (ages 4-7)	Children (ages 8-11)	Adults
Forward Digit Span	.35**	.11	.03
Backwards Digit Span	.43**	- .10	- .05
Flanker difference score	.14	- .28*	.06
Go/No-Go commission errors	- .09	.13	- .20
Simon difference score	.06	- .05	- .02

* $p < .05$.
** $p < .01$.

required to filter out the distracting information. Difference scores were used to control for large individual differences in speed of responding. Without such a subtraction, a high or low score could be attributed to the participant simply being a slow or fast responder.

Flanker Task. The Flanker data of 8 younger children and 2 older children were not analyzed due to high error rate (30% errors on trials). Of the 8 younger children removed from analysis, on average, 62% of the errors they made were on incongruent trials. An analysis of variance revealed that there was a significant difference in Flanker performance between the three age groups, F (2, 134) = 12.70, $p < .001$. Adults (M = 57.04 ms, SD = 22.40) had significantly lower Flanker difference scores than young children (M = 121.11

ms, *SD* = 84.32) and older children (*M* = 125.91 ms, *SD* = 97.35) (*p*'s < . 001), indicating that children had less efficient interference control than adults. There was no significant difference in Flanker performance between younger children and older children (*p* = .96)

As shown in Figure 10 and Table 4, Flanker performance correlated significantly with average categorization performance in older children *r* (53) = - .28, *p* = .02, but not in younger children, *r* (30) = .14, *p* = .23, and adults *r* (52) = .06, *p* = .34[3]. Modeling analysis confirmed this relationship by showing that AIC fit to the frequency model (i.e., good categorization performance) was associated with flanker performance, *r* (53) = .36, *p* = .004 (see Figure 11). This relationship was not evident in younger children and adults.

A one-way ANOVA was conducted to examine Flanker performance among the older children and adults whose categorization performance fell within the top 20% (*n* = 12) of their age group. Results revealed no significant difference in Flanker performance (i.e., reaction time difference scores) between high-performing older children (*M* = 65.76 ms, *SD* = 45.16) and adult (*M* = 54.42 ms, *SD* = 17.63) rule-learners, *F* (1, 22) = .65, *p* = .43. This finding indicates that older children classified as strong rule-learners could perform at a similar level to adults on the Flanker task.

---

[3]Correlation between [Incon.-Neutral] Flanker scores and categorization was marginally significant in younger and older children (*p* = .05 and .07, respectively). The correlation between Flanker errors and categorization was marginally significant in older children (*p* = .05).

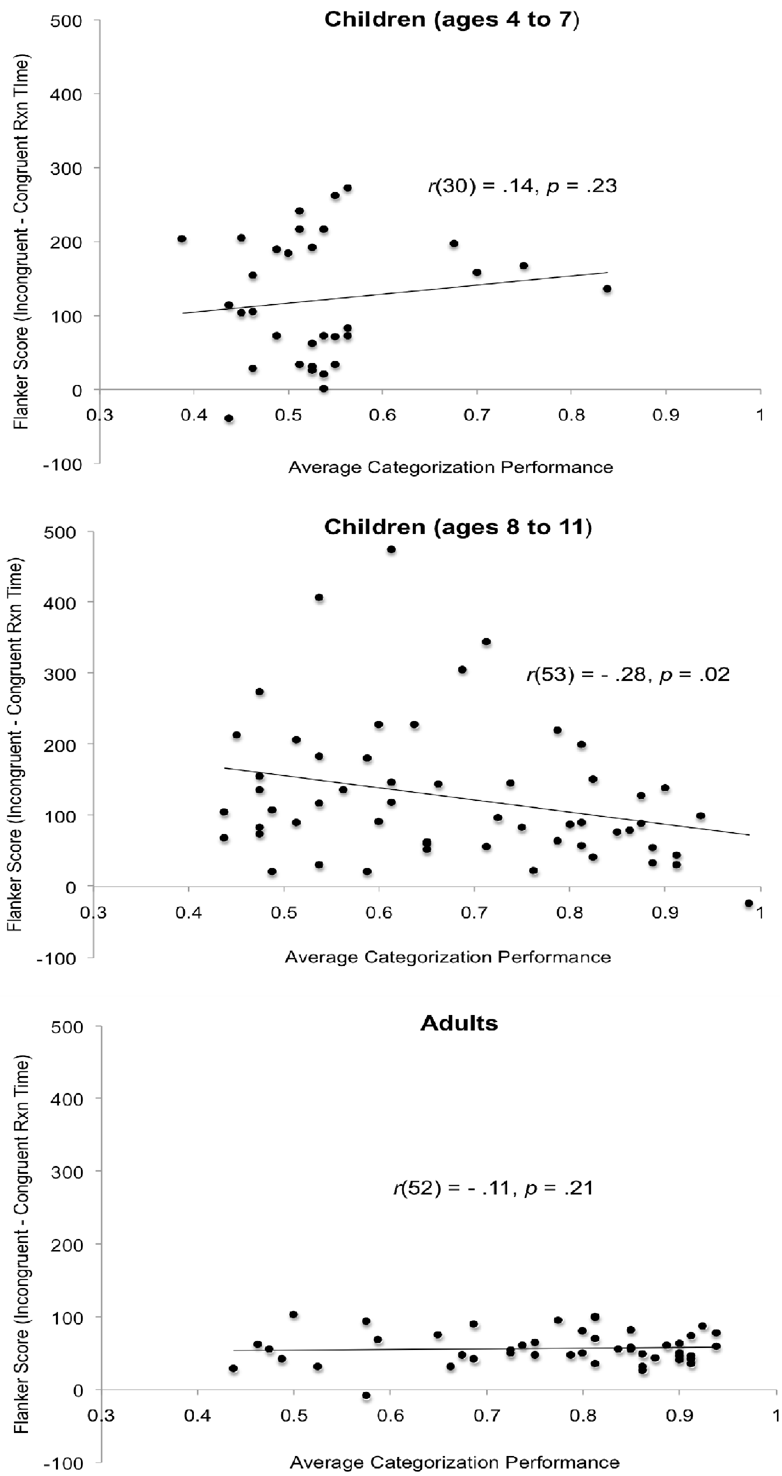

Figure 10. Correlation between categorization performance and flanker scores.

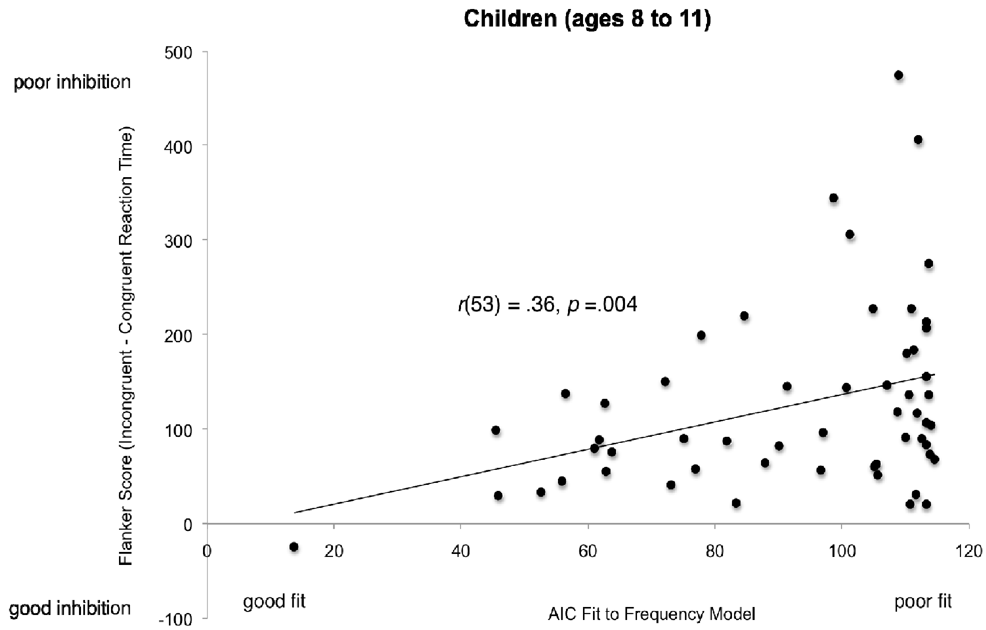

Figure 11. The correlation between flanker scores and AIC fit to the frequency model in older children.

Go/No-Go Task. Adults (M = .46, SD = .80) made fewer commission errors on the Go/No-Go task compared to older children (M = 1.54, SD = 1.30) and younger children (M = 2.20, SD = 1.68), indicating that children had less efficient response suppression than adults. As displayed in Table 4, Go/No-Go commission errors did not correlate with average categorization performance in any of the age groups. These results indicate the form of inhibitory control used in the Go/No-Go task (i.e., response suppression) may not be associated with rule-based category learning.

Simon Task. The Simon data of 1 younger child and 2 older children were not analyzed due to high error rate (30% errors on trials). Adults (M = 39.33 ms, SD = 32.87) had lower Simon difference scores than younger children (M = 98.74 ms, SD = 96.22) and older children (M = 69.87 ms, SD = 50.68), indicating interference control on the Simon task improved with age. Simon task performance did not correlate with average categorization performance in any of the age groups. Even though the Simon task taps into the same form of inhibitory control as the Flanker task (i.e., interference control), task differences may explain the non-significant correlation on the Simon task[4].

Working Memory. Forward and backward digit span performance correlated with average categorization performance in younger children, $r(40)$ = .35 for forward digit span and, $r(40)$ = .43 for backward digit span, ($p < .01$ for both tasks), but not in older children and adults (see Table 4). This result is likely due to the fact that the digit span task is challenging enough to accurately measure working memory capacity in younger children, but is not difficult enough to display differences in performance among older children and adults (i.e., there was a narrow range of digit span scores in older children and adults).

---

[4]Simon[Incon-Neutral] scores did correlate with categorization (p =.01) in adults.

Discussion

Previous research has outlined age-related differences in rule-based category learning but has yet to investigate the link between categorization performance and inhibitory control in children. The current study examined category learning, inhibitory control, and working memory in young children (ages 4 to 7), middle-school children (ages 8 to 11), and adults. As predicted there was developmental variance in the acquisition of rule-based category knowledge, in that categorization performance improved with age. However, when directly comparing older children and adults who identified the correct rule-based strategy early on in the task, no performance deficit was found between age groups. In other words, the best-performing older children learned as well as the best-performing adults. Model-based analyses suggested that the developmental differences in performance were due to young children's general inability to inhibit the salient, but incorrect rule during the categorization task. In addition, findings showed that older children who performed well on the rule-based categorization task were also those who showed better inhibitory control on the Flanker task. This finding did not hold true for younger children and adults, most likely because during early childhood inhibition capacity is just starting to develop and in adulthood inhibition capacity is fully developed. Furthermore, the majority of young children could not solve the rule-based task and the adults solved the task with no problem. Given the lack of variance in categorization performance abilities among this age group, the relationship between inhibitory control ability and rule-based category learning could not be fully explored.

Performance on the Go/No-Go task and Simon task was not associated with rule-based performance in any age group, alluding to the possibility that task differences and certain subtypes of inhibition (i.e., interference control) may have a stronger relationship with category learning than others. Lastly, younger children who solved the rule-based task were also those who showed better working memory on the digit span task. This relationship did not hold true for older children and adults, most likely due to the fact that the digit span task was not challenging enough to detect differences in working memory capacity. It is also possible that since the categorization stimuli used in the current study varied in only two dimensions, the categorization task was not very taxing to working memory. It may be that working memory effects would be found in older children and adults if categorization stimuli consisted of multiple dimensions.

Rule-Based Category Learning

Minda, Desroches, and Church (2008) found that children were able to learn simple, single-dimensional rules at the same level as adults, but adults outperformed children on categories that were optimally learned by a complex rule. These results are consistent with the findings of the current study, which involved a more complicated category set, in which the suboptimal rule was associated with a salient feature. In line with the findings of Minda et al., the present study found that children struggled with rule-based category learning in comparison to adults, with younger children showing the most difficulty in acquiring the correct rule.

Additional support for the age-related differences in rule-based category learning found in the current study comes from research investigating categorization performance in young children (ages 4 to 6 years) and adults when asked to learn five-dimensional categories (Minda, Miles, & Rabi, submitted). Findings showed that adults tended to identify and use the correct rule, whereas children were less likely to classify the stimuli according to the correct rule, unless it corresponded to a perceptually salient feature. Similarly, in the present study modeling analysis showed that many young children could not learn the rule-based task because they allowed the salient, incorrect rule guide their categorization judgments. Furthermore, these findings suggest that young children can identify rules when they correspond to dimensions which most capture attention. However, if identifying the rule requires hypothesis testing and inhibitory control abilities that are not yet fully developed, young children may rely on an imperfect rule to solve the task.

In addition to examining category learning in young children, research has also been conducted looking at category learning in middle childhood. Huang-Pollock and colleagues (2011) found that adults outperformed children (ages 8 to 13) on a rule-based categorization task because children persistently allowed the irrelevant dimension to guide their categorization judgments. In contrast, adults were able to inhibit the irrelevant dimension to their benefit. The present findings are comparable to those of Huang-Pollock et al. because the individual learning curve data from the current study illustrated that there was a group of older children who struggled with finding the correct rule and relied on the irrelevant dimension to make categorization judgments. Model-based analysis confirmed this conclusion by showing that the frequency model (i.e., model fitting the use of the correct rule) better fit the data of adults, compared to younger and older children. However, the present study revealed that even though adults outperformed older children on the categorization task and learned the task at a faster rate than older children, a large portion of 8 to 11-year-olds were successful at finding the correct rule. Therefore, it appears that by middle childhood the cognitive processes involved in rule-based category learning have matured enough to allow for successful performance, however these processes are not fully developed and so some older children may still struggle with the task. This finding is consistent with the developmental literature that finds that executive functioning abilities continue to develop across childhood because it is not until late adolescence that the prefrontal cortex fully develops (Bunge & Zelazo, 2006).

For those older children who performed well on the rule-based task, a closer look at their individual performance profiles revealed an interesting result. When the categorization performance of the top older children and the top adult rule learners (i.e., the 12 participants in each age group with the highest average categorization performance) were compared, no significant difference in rule learning was found. Furthermore, it appears that some older children can learn rules as accurately and fast as adults, as long as they possess the hypothesis testing skills needed to test rules and the inhibition capacity required to inhibit suboptimal rules.

To confirm that age was not the driving factor behind why some older children could learn the rule-based categories, yet others struggled, the relationship between age and categorization performance within each group of participants was examined. Results revealed that age was not associated with categorization performance for both older children and adults. However, within the younger age group, categorization performance did improve with age. These results illustrate that in contrast to young children, older children and adults possess the cognitive abilities needed to learn the rule-based task, independent of age.

Even though executive functioning continues to mature with age, rapid changes and developmental milestones occur early in childhood, making the relationship between age and rule-based category learning more complex. Bunge and Zelazo (2006) have shown that rapid changes in rule use occur between 2 and 5 years of age, reflecting the growth of the prefrontal cortex. By 3 years, children can represent a pair of rules, but they have difficulty switching between two incompatible pairs of rules on the Dimensional Change Card Sort task. The marked improvements in rule use during early childhood may explain why the present study found improvements in categorization with age in younger children.

Category Learning & Inhibitory Control

In an effort to identify what separates strong rule-based learners from weak rule-based learners, inhibitory control performance was measured. Given the fact that rule-based category learning involves the ability to inhibit one rule in favor of another, it was predicted that children and adults who performed well on the categorization task would also be those who exhibited strong inhibitory control abilities on the three inhibition tasks.

Beginning with the Flanker task, adults displayed better interference control (i.e., lower difference scores) than both younger children and older children. This indicates that it, in comparison to adults, it took children longer to make responses on incongruent trials. Older children and younger children had similar Flanker difference scores, however, this was most likely due to the fact that eight young children were removed from analysis due to high error rate. A closer look at these eight children revealed that the majority of their Flanker errors occurred on incongruent trials, indicating that they had poor inhibitory control.

Predictions were partially supported in that Flanker task performance was associated with average categorization performance in older children, but this relationship did not hold true for younger children and adults. For the younger age group, average categorization performance was just above chance, indicating that the majority of young children were unsuccessful at learning the rule-based categorization task. Since there was minimal variability in categorization performance among the younger age group (i.e., only 4 out of 42 children had an average categorization performance above 70%), the relationship between category learning and inhibitory control could not truly be explored in the younger age group. At the other end of the age spectrum, the opposite situation holds true. There was no relationship between average categorization performance and Flanker scores in adults, most likely because the majority of adults solved the categorization task with no difficulty and as such there was a limited range of performance. Additionally, by adulthood, inhibitory abilities have matured, as evidenced by the narrow range of Flanker scores in adults. Given the lack of variance in both categorization and Flanker scores among adults, it is understandable that the relationship was not significant.

Of particular interest is the Flanker performance of older children because the variability in categorization performance among this age group allowed for a closer look at the rule-learning/inhibitory control relationship. Result revealed that older children who performed well on the rule-based task were also those who displayed good Flanker performance (i.e., similar reaction times on both congruent and incongruent trials). In addition, modeling analysis confirmed this relationship by showing that older children who were best fit by the frequency model were also those who displayed the best Flanker performance. Put another way, older children who struggled with identifying the correct rule during the categorization task and were not fit well to the frequency model were also more likely to struggle with inhibiting responses on the Flanker task.

Go/No-Go performance and Simon task performance improved with age, indicating that inhibitory control tends to improve with age. In contrast to the predictions of this study, performance on the Go/No-Go task and Simon task were not associated with rule-based performance in any age group. These findings may be explained by examining differences in the inhibition tasks and by exploring the relationship between certain subtypes of inhibition (i.e., responses suppression and interference control) and rule-based category learning. In support of these findings, Maddox et al. (2010) gave older adults two types of inhibition tasks to complete (i.e., the Stroop task and the Wisconsin Card Sort task). Only Stroop performance was associated with rule-based performance. Furthermore, the Stroop task measures the subtype of inhibitory control known as interference control, and so it is possible that inhibition tasks measuring interference control may be more related to rule-based learning than tasks measuring response suppression.

Neural Mechanisms Involved in Inhibitory Control

It is useful to investigate the brain regions involved in inhibitory control and category learning in order to better explain the relationship between rule-based category learning and inhibition capacity in children and adults. Bunge, Dudukovic, Thomason, Vaidya, and Gabrieli (2002) used fMRI to identify developmental changes in brain activation related to performance on inhibitory control tasks in children ages 8-12 and adults. Results revealed that children were more susceptible to interference and less able to inhibit inappropriate response than were adults. As well, children failed to activate a region in the right ventrolateral prefrontal cortex that was recruited for the inhibitory control tasks by adults. Adleman et al, (2002) also found that in the Stroop task, parietal lobe activation reached adult levels by adolescence, but prefrontal cortex activation continued to develop in this period. Such findings might help to explain why there was so much variance in performance on the categorization and Flanker task in older children. Furthermore, older children, who failed to learn the rule based task and struggled with the Flanker task, may have been performing in this manner because they failed to activate regions in the prefrontal cortex that are necessary for proper inhibitory control.

Additional evidence for this claim comes from lesion studies showing that prefrontal lesions in adults and nonhuman primates lead to impairments in inhibitory control (Luria, 1966; Miller and Cohen, 2001). With reference to rule-based category learning, Schnyer, Maddox, Ell, Davis, Pacheco, and Verfaellie

(2009) examined categorization performance in patients with prefrontal lesions. Findings showed that prefrontal patients were impaired at rule-based categorization and showed impaired inhibition as measured by the Wisconsin Card Sort task. Based on these findings it seems reasonable to suggest that prefrontal cortical changes associated with development might be responsible for rule-based category learning deficits.

Bunge and Zelazo (2006) developed a brain-based account of rule use in childhood to account for past findings. They state that the developmental changes in rule use reflect the rate of development of the prefrontal cortex. As well, Bunge and Zelazo report that age-related improvements in rule use follow a set pattern: children use a single rule to switching between two rules to switching between two incompatible pairs of rules. These increasingly complex hierarchies of rules are accompanied by greater involvement of the prefrontal cortex. Furthermore, since the prefrontal cortex develops later than other areas and has been implicated in inhibitory control, it follows that maturation of this brain area may be a limiting factor in the performance on rule-based categorization tasks.

Subtypes of Inhibitory Control

Given the finding that the prefrontal cortex has been implicated in both inhibitory control and rule-based learning, it is important to determine the specific neural regions involved in each of the subtypes of inhibitory control to determine whether one type of inhibition is more related to category learning than another type. A distinction has consistently been made in the literature between response suppression (i.e., the ability to inhibit a dominant or prepotent response) and interference control (i.e., the ability to inhibit a response to competing, irrelevant information) (Wolfe & Bell, 2004; Barkley, 1997). Nigg (2000) proposed that the two subtypes of inhibitory control might be mediated by different neural circuits. For response suppression, learning is mediated by a circuit that includes the lateral and orbital prefrontal cortex and the premotor cortex. Support for this proposal comes from research showing that the lateral orbital prefrontal cortex and its associated subcortical structures have been shown to play a role in Go/No-Go response deficits in children with ADHD (Casey et al., 1997). Whereas for interference control, learning is mediated by a circuit that includes the anterior cingulate, dorsolateral prefrontal cortex/premotor cortex, and the basal ganglia. Cabeza and Nyberg (1997) have shown that Stroop responding in adults activates the dorsolateral prefrontal cortex and appears to depend even more heavily on the anterior cingulate gyrus.

Interestingly, the neural circuit involved in rule-based category learning appears to closely resemble the neural circuit involved in interference control but not response suppression. Rule-based learning has been shown to be mediated by a circuit that includes not only the prefrontal cortex, but the anterior cingulate, and the head of the caudate nucleus as well (Ashby et al., 1998; Ashby & Waldron, 1999; Ashby & Ell, 2001). Additionally, Kolb and Whishaw

(1990) have shown that the basal ganglia is also involved in rule-based category learning, as evidenced by the fact that individuals with basal ganglia dysfunction are impaired in rule-based tasks. The fact that tasks involving rule-based category learning and interference control activate similar brain regions helps to explain the relationship found between category learning and inhibitory control. More specifically, results from the present study showed that rule-based learning was related to Flanker performance (i.e., a measure of interference control) but not Go/No-go performance (i.e., a measure of response suppression) in older children.

Sources of Variability across Tasks

While Flanker task results suggest that interference control may be related to rule-based category learning, the current study found no relationship between Simon task scores (i.e., another measure of interference control) and categorization performance. Furthermore, it is possible that task differences may help to explain the complex relationship between category learning and inhibitory control. At first glance, the Flanker task and Simon task appear to measure the same underlying construct, the ability to select the appropriate response from a set of response alternatives. Even though these two tasks make use of similar cognitive processes and are supported by similar brain regions, they differ in their information processing architecture. Stins, Polderman, Boomsma, and de Geus (2007) point out that one key difference concerns the nature of the attentional movements in both tasks. In the Flanker task, attention has to focus on the target, essentially narrowing in attention from a higher-order to a lower-order level of representation. In contrast, in the Simon task, attention has to make a same-level shift to the target stimulus. A second key difference is that in the Flanker task, the flow of information proceeds along the same channel, whereas stimulus features are processed along separate channels in the Simon task (task features belong to different perceptual dimensions, i.e., colour and location). Based on these tasks differences, it appears that the Flanker task may share more similarities with the categorization task than the Simon task. This may be the case because the rule-based task involves categorizing patterns that vary in line frequency and orientation and the flow of information appears to proceed along the same channel.

Additional support for the claim that the Flanker task and Simon task involve different cognitive operations comes from research by Salthouse, Siedlecki, and Krueger (2006) showing that several indices of interference control were not related to one another. Along the same lines, Stins, Polderman, Boomsma, and de Geus (2005) found that the amount of interference (i.e., the sizes of the Stroop, Simon, and Flanker effects) were uncorrelated. Stins et al. proposed that the Flanker and Simon task may make use of similar, but not quite identical, cortical regions or cognitive resources.

Category Learning & Working Memory

In partial support of predictions, categorization performance was associated with working memory in younger children, however this relationship did not hold true for older children and adults. Younger children who solved the rule-based task were also those who showed better working memory on the digit span task. This finding is supported by research showing that individuals with high working memory capacity are faster and better at learning rule-based categories than individuals with low working memory capacity (DeCaro, Thomas, and Beilock, 2008). It is possible that older children and adults failed to show this relationship because the digit span task was not challenging enough to detect differences in working memory capacity.

Limitations & Future Directions

Results of the present study revealed that the majority of young children struggled with the categorization task. With so few children learning the task it becomes difficult to explore the differences between rule-learners and non-rule-learners. If this study were to be replicated, it would be useful to include more trials in the categorization task in order to get a better idea of performance capabilities. It is possible that if provided with enough trials to complete, younger children may have been able to solve the task. Given the limited attention span of young children, only a limited number of trials could be used in the present study. In the future, it may be advantageous to break up the categorization task into multiple testing sessions.

As an alternative to employing a longer version of the categorization task used in the present study, future research might also benefit from using a different type of categorization task. Minda and colleagues (2008) used a rule-based category set created by Shepard, Hovland, and Jenkins (1961) in their study, and results showed that young children could learn the categories. In the single-dimensional category set used, perfect performance could be attained by the formation of a straightforward verbal rule (e.g., *if* black *then* Category 1). Young children were able to learn this category set because the rule was simple, easy to describe, and directly related to perception. If the present study was replicated using the Shepard, Hovland, and Jenkins (1961) category set, it is predicted that young children who performed well on the task would also be those who displayed strong inhibitory control skills.

To further understand the role of hypothesis testing in rule-based category learning, it would be useful to further investigate hypothesis testing abilities in young children. Since young children in the current study struggled with identifying the correct rule in the categorization task, future research could examine whether categorization performance would improve if young children were first asked to verbally describe all dimensions of the categorization stimuli before they began the actual task. It is predicted that this type of study design will assist the young children with hypothesis testing and improve overall performance on the categorization task.

In order to accommodate the cognitive capabilities of young children, certain types of inhibition tasks were chosen for the present study. Future research may benefit from using different types of inhibition tasks, like the Stroop task, to examine whether certain forms of inhibitory control are more related to rule-based category learning than others. Lastly, the current study consisted of young children (ages 4 to 7), middle-school children (ages 8 to 11) and adults (ages 18+). In order to fully explore the nature of the trajectory from child-like learning to adult-like learning, it would be useful for future research to investigate the relationship between category learning and executive functioning in adolescents (ages 12 to 17).

Conclusions

The current study examined rule-based category learning in early childhood, middle childhood, and adulthood. Results revealed that categorization performance improved with age. More specifically, most young children struggled with the rule-based task and could not learn the rule. In contrast, there was a lot of variability in the performance of older children, with a large portion of children showing evidence of category learning. Lastly, the majority of adults learned the category set very quickly, showing little difficulty in identifying the correct rule. A comparison of older children and adults who performed well on the categorization task revealed that no performance deficit was found between groups. This shows that by middle childhood, children can learn rules as accurately and quickly as adults, as long as they posses the hypothesis testing skills needed to test rules and the inhibition capacity required to inhibit suboptimal rules. Model-based analyses confirmed that the developmental differences in performance were due to children's greater difficulty in inhibiting the salient, but incorrect rule during the categorization task compared to adults.

Additionally, findings revealed that older children who struggled with the rule-based categorization task were also those who showed weaker inhibitory control on the Flanker task. This relationship was not found in younger children and adults, most likely because there was limited variance in the categorization performance abilities of young children and adults and so the true relationship between inhibitory control ability and rule-based category learning could not be fully explored. Performance on the Go/No-Go task and Simon task were not associated with rule-based performance in any age group, suggesting that task differences and certain subtypes of inhibition (i.e., interference control) may have a stronger relationship with category learning than others. Lastly, findings revealed that strong categorization performance was associated with a larger working memory capacity in young children, but not in older children and adults. All together, the current study has mapped the performance of typically developing children and adults and has highlighted the complex relationship between rule-based category learning and executive functioning.

References

Adleman, N., Menon, V., Blasey, C., White., C., Warsofsky, I., Glover, G., & Reiss, A. (2002). A developmental fMRI study of Stroop Color-Word task. *Neuroimage, 16,* 61-75.

Akaike, H. (1974). A new look at the statistical model identification. *Transactions on Automatic Control, 19,* 716-723.

Ashby, F. G., Alfonso-Reese, L. A., Turken, A. U., & Waldron, E. M. (1998). A neuropsychological theory of multiple systems in category learning. *Psychological Review, 105*, 442-481.

Ashby, F. G., & Ell, S. W. (2001). The neurobiology of human category learning. *Trends in Cognitive Sciences, 5,* 204-210.

Ashby, F. G., & Gott, R. E. (1988). Decision rules in the perception and categorization of multidimensional stimuli. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 14,* 33-53.

Barkley, R. A. (1997). *ADHD and the nature of self-control.* New York: Guilford Press.

Berlin, L. & Bohlin, G. (2002). Response inhibition, hyperactivity, and conduct problems among preschool children. *Journal of Clinical and Adolescent Psychology, 31,* 242-251.

Botvinick, M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring versus selection-for-action in anterior cingulated cortex. *Nature, 402*, 179-181

Bruner, J. S., Goodnow, J. J., and Austin, G. A. (1956). *A Study of Thinking.* New York: Wiley.

Bunge, S. A., Dudukovic, N. M., Thomason, M. E., Vaidya, C. J., & Gabrieli, D. E. (2002). Immature frontal lobe contributions to cognitive control in children: evidence from fMRI. *Neuron, 33*, 301-311.

Bunge, S. A. & Zelazo, P. D. (2006). A brain-based account of the development of rule use in childhood. *Current Directions in Psychological Science, 15*, 118-121.

Cabeza, R., & Nyberg, L. (1997). Imaging cognition: An empirical review of PET studies with normal subjects. *Journal of Cognitive Neuroscience, 9,* 1-26.

Carlson, S. M., Moses, L. J., & Hix, H. R. (1998). The role of inhibitory processes in young children's difficulties with deception and false belief. *Child Development, 69,* 672-691.

Carter, J. D., Farrow, M., Silberstein, R. B., Stough, C., Tucker, A., & Pipingas, A. (2003). Assessing inhibitory control: A revised approach to the stop signal task. *Journal of Attention Disorders, 6,* 153-161.

Carver, A. C., Livesey, D. J., & Charles, M. (2001). Age related changes in inhibitory control as measured by stop signal task performance. *International Journal of Neuroscience, 107*, 43-61.

Casey, B. J., Trainor, R. J., Orendi, J. L., Schubert, A. B., Nystrom, L. E., Giedd, J. N., Castellanos, F. X., Haxby, J. V., Noll, D.C., Cohen, J.D., Forman, S. D., Dahl, R. E. & Rapoport, J. L. (1997). A developmental functional MRI study of prefrontal activation during performance of a go-no-go task. *Journal of Cognitive Neuroscience, 9*(6), 835-847.

Casey, B. J., Davidson, M.C., Hara, Y., Thomas, K. M., Martinez, A., Galvan, A., et al. (2004). Early development of subcortical regions involved in non-cued attention switching. *Developmental Science, 7,* 534-542.

Couchman, J., Coutinho, M., & Smith, D. (2010). Rules and resemblance: Their changing balance in the category learning of humans (*Homo sapiens)* and monkeys (*Macaca mulatta). Journal of Experimental Psychology: Animal Behavior Processes, 36*(2), 172-183.

DeCaro, M., Thomas, R., & Beilock, S. (2008). Individual differences in category learning: Sometimes less working memory capacity is better than more. *Cognition, 107*, 284-294.

Dempster, F. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review, 12,* 45-75.

Dowsett, S. M., & Livesey, D. J. (2000). The development of inhibitory control in preschool children: effects of “executive skills” training. *Developmental Psychobiology, 36*(2), 161-174.

Drew, E. A. (1975). Go-no-go learning after frontal lobe lesions in humans. *Cortex, 11,* 8016.

Eriksen, C. W., & Schultz, D. W. (1979). Information processing in visual search: A continuous flow conception and experimental results. *Perception & Psychophysics, 25,* 249-263.

Espy, K. A., & Bull, R. (2005). Inhibitory processes in young children and individual variation in short-term memory. *Developmental Neuropsychology, 28*(2), 669-688.

Filoteo, J. V., Maddox, W. T., Ing, A. D., Zizak, V., & Song, D. D. (2005). The impact of irrelevant dimensional variation on rule-based category learning in patients with Parkinson’s disease. *Journal of International Neuropsychological Society, 11*(5), 503-513.

Gathercole, S. E. (1999). Cognitive approaches to the development of short-term memory. *Trends in Cognitive Science, 3,* 410-419.

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegman, Z. (2004). Working memory skills and educational attainment: Evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology, 18*, 1-16.

Grieve, S. M., Williams, L. M., Paul, R. H., Clark, C. R., & Gordon, E. (2007). Cognitive aging, executive function, and fractional anisotropy: A diffusion tensor MR imaging study. *AJNR American Journal of Neuroradiology, 28*(2), 226-235.

Hayes, B. K., Foster, K., & Gadd, N. (2003). Prior knowledge and subtyping effects in children's category learning. *Cognition, 88*, 171-199.

Hazeltine, E., Poldrack, R., & Gabrieli, J. D. E. (2000). Neural activation during response competition. *Journal of Cognitive Neuroscience, 12*, 118-129.

Huang-Pollock, C. L., Maddox, W. T., & Karalunas, S. L. (2011). Development of implicit and explicit category learning. *Journal of Experimental Child Psychology, 109*, 321-355.

Knowlton, B. J., Mangels, J. A., & Squire, L. R. (1996). A neostriatal habit learning system in humans. *Science, 273,* 1399-1402.

Kolb, B., & Whishaw, I. Q. (1990). The frontal lobes. In B. Kolb & I. Q. Whishaw (Eds.), *Fundamentals of human neuropsychology* (3rd ed., pp. 463-501). New York: Freeman.

Konishi, S., Nakajima, K., Uchida, I., Kikyo, H., Kameyama, M. & Miyashita, Y. (1999). Common inhibitory mechanism in human inferior prefrontal cortex revealed by event-related functional MRI. *Brain, 122*, 981-991.

Lewandowsky, S. (2011). Working memory capacity and categorization: Individual differences and modeling. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*, 720-738.

Lindqvist, S. & Thorell, L. B. (2009). Manipulations of task difficulty in inhibitory control tasks. *Child Neuropsychology, 15*, 1-7.

Luria, A. R. (1966). Higher cortical functions in man. New York: Basic Books.

Maddox, W. T., Pacheco, M. R., Zhu, B., & Schnyer, D. M. (2010). Rule-based and information-integration category learning in normal aging. *Neuropsychologia, 48,* 2998-3008.

Miller, E. K., and Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review Neuroscience*, *12*, 538-549.

Minda, J. P., Desroches, A.S., & Church, B. A. (2008). Learning rule-described and non-rule-described categories: A comparison of children and adults. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 34,* 1518-1533.

Minda, J. P., Miles, S. J., & Rabi, R. R. (submitted). Learning categories via rules and similarity: Comparing adults and children. *Memory & Cognition*.

Minda, J. P., & Smith, J. D. (2001). Prototypes in category learning: The effects of category size, category structure, and stimulus complexity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 775-799.

Mueller, S. T. (2010). The Psychology Experiment Building Language, Version 0.11.

Murphy, G. L. (2002). *The big book of concepts.* Cambridge, MA: MIT Press.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126*(2), 220-246.

Pierce, J. (2007). Psychophysics software in python. *Journal of Neuroscience Methods, 162*, 8-13.

Quinn, P. C., Palmer, V., & Slater, A. M. (1999). Identification of gender in domestic-cat faces with and without training: Perceptual learning of a natural categorization task. *Perception, 28*, 749-763.

Racine, C. A., Barch, D. M., Braver, T. S., & Noelle, D. C. (2006). The effect of age on rule-based category learning. *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition, 13*(3-4), 411-434.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F. I. M. Craik, & T. A. Salthouse (Eds.), *Handbook of aging and cognition* (pp. 1-90). Nahwah: Lawrence Erlbaum Associates.

Ridderinkhof, K. R., Span, M. M., & van der Molen, M. W. (2002). Perseverative behavior and adaptive control in older adults: Performance monitoring, rule induction, and set shifting. *Brain and Cognition, 49*(3), 382-401.

Salthouse, T. A., Siedlecki, K. L., & Krueger, L. E. (2006). An individual differences analysis of memory control. *Journal of Memory and Language, 55,* 102-125.

Schnyer, D. M., Maddox, W. T., Ell, S., Davis, S., Pacheco, J., & Verfaellie, M. (2009). Prefrontal contributions to rule-based and information-integration category learning. *Neuropsychologia, 47*(13), 2995-3006.

Shepard, R. N., Hovland, C. I., & Jenkins, H. M. (1961). Learning and memorization of classifications. *Psychological Monographs: General and Applied, 75*(13, Whole No. 517), 1-42.

Simon, J. R., & Rudell, A. P. (1967). Auditory S-R compatibility: Reaction time as a function of ear-hand correspondence and ear-response-location correspondence. *Journal of Applied Psychology, 51,* 300-304.

Sloutsky, V. M., & Fisher, A. V. (2004). Induction and categorization in young children: A similarity-based model. *Journal of Experimental Psychology: General, 133,* 166-188.

Stins, J. F., Polderman, J. C., Boomsma, D. I., & de Geus, E. C. J. (2005). Response interference and working memory in 12-year old children. *Child Neuropsychology, 11,* 191-201.

Stins, J. F., Polderman, J. C., Boomsma, D. I., & de Geus, E. C. J. (2007). Conditional accuracy in response interference tasks: Evidence from the Eriksen flanker task and the spatial conflict task. *Advances in Cognitive Psychology, 3,* 409-417

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 28,* 643-662.

Stuss, D. T., & Knight, R. T. (2002). *Principles of frontal lobe function.*

van den Wildenberg, W. P., Wylie, S. A., Forstmann, B. U., Burle, B., Hasbroucq, T., & Ridderinkhof, K. R. (2010). To head or to heed? Beyond the surface of selective action inhibition: A review. *Frontiers in Human Neuroscience, 4:* 222.

Waldron, E. M., & Ashby, F. G. (2001). The effects of concurrent task interference on category learning: Evidence for multiple category learning systems. *Psychonomic Bulletin & Review, 8,* 168-176.

Wickens, T, D. Models for behavior: Stochastic processes in psychology. San Francisco: W. H. Freeman; 1982.

Wolfe, C. D., & Bell, M. A. (2004). Working memory and inhibitory control in early childhood: Contributions from physiology, temperament, and language. *Developmental Psychobiology, 44,* 68-83.

Zeithamova, D., & Maddox, W. (2006). Dual-task interference in perceptual category learning. *Memory & Cognition, 34*, 387-398.

Zelazo, P. D., & Frye, D. (1998). Cognitive complexity and control: II. The development of executive function in childhood. *Current Directions in Psychological Science, 7,* 121-126.

Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development, 11,* 37-63.

Appendix A

Department of Psychology The University of Western Ontario
Room 7418 Social Sciences Centre,
London, ON, Canada N6A 5C1
Telephone: (519) 661-2067Fax: (519) 661-3961

Use of Human Subjects - Ethics Approval Notice

Review Number	11 09 12	**Approval Date**	11 09 08
Principal Investigator	Paul Mind/Rachel Rabi	**End Date**	12 08 31
Protocol Title	Learning to categorize pictures		
Sponsor	n/a		

This is to notify you that The University of Western Ontario Department of Psychology Research Ethics Board (PREB) has granted expedited ethics approval to the above named research study on the date noted above.

The PREB is a sub-REB of The University of Western Ontario's Research Ethics Board for Non-Medical Research Involving Human Subjects (NMREB) which is organized and operates according to the Tri-Council Policy Statement and the applicable laws and regulations of Ontario. (See Office of Research Ethics web site: http://www.uwo.ca/research/ethics/)

This approval shall remain valid until end date noted above assuming timely and acceptable responses to the University's periodic requests for surveillance and monitoring information.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the PREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of research assistant, telephone number etc). Subjects must receive a copy of the information/consent documentation.

Investigators must promptly also report to the PREB:
a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to the PREB for approval.

Members of the PREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the PREB.

Clive Seligman

Clive Seligman Ph.D.

Chair, Psychology Expedited Research Ethics Board (PREB)

The other members of the 2011-2012 PREB are: Mike Atkinson (Introductory Psychology Coordinator), Rick Goffin, Riley Hinson Albert Katz (Department Chair), Steve Lupker, and TBA (Graduate Student Representative)

CC: UWO Office of Research Ethics

This is an official document. Please retain the original in your files

RAHEL RABI

Education

M. Sc. Psychology, The University of Western Ontario, London, Ontario, in progress

B. Sc. Honours, Psychology, The University of Western Ontario, London, Ontario, 2009

Teaching Experience

Teacher's Assistant, Department of Psychology, The University of Western Ontario, September 2010 to April 2012

- Research in Cognitive Psychology, Fall 2010, Fall 2011
- Research Methods in Psychology, Winter 2011
- Language Development, Winter 2012

Scholarships & Awards

Natural Sciences and Engineering Research Council of Canada, $105,000, September 2012 – August 2015

Graduate Thesis Research Award, $750, January 2012 – August 2012

Natural Sciences and Engineering Research Council of Canada, $17,500, May 2011 – April 2012

Ontario Graduate Scholarship, $15,000, Declined, May 2011

Western Graduate Research Scholarship, $750, September 2011 – December 2011

Queen Elizabeth II Graduate Scholarship in Science and Technology, $10,000, September 2010 – April 2011

Western Graduate Research Scholarship, $8,000, September 2010 – April 2011

Natural Sciences and Engineering Council of Canada Undergraduate Student Research Award, $4,500, May 2010 – August 2010
Grad Pact Award, $250, May 2009

Natural Sciences and Engineering Council of Canada Undergraduate Student Research Award, $4, 500, May 2009 – August 2009

Western Scholarship of Distinction, $1,500, September 2005 – April 2006

Research

Peer Reviewed Publications

Nadler, R. T., **Rabi, R.**, & Minda, J. P. (2010). Better mood and better performance: Learning rule-described categories is enhanced by positive mood. *Psychological Science. 21,* 1770-1776.

Minda, J. P., Miles, S. J., & **Rabi, R.** (submitted). Learning categories via rules and similarity: Comparing adults and children. *Memory & Cognition.*

Presentations

Miles, S. J., **Rabi, R.**, & Minda, J. P. (2012, June). To what extent does category learning rely on executive functions? Evidence from child development and concurrent tasks. *Talk presented at the 2012 Annual Meeting of the Canadian Society for Brain, Behaviour and Cognitive Science*, Kingston, ON.

Rabi, R., & Minda, J. P. (2012, May). Age-related improvements in rule-based categorization: The role of inhibitory control. *Poster presented at the 24th Annual American Psychological Society Convention*, Chicago, IL.

Rabi, R. (2012, March). Rule-based category learning in children: The role of inhibitory control. *Talk presented a t the 25th Annual Western Research Forum*, London, ON.

Miles, S. J., **Rabi, R.,** & Minda, J. P. (2011, March). Suboptimal rule use and fully developed prototype abstraction by children: Evidence for two learning systems. *Talk presented at the 2011 Society for Research and Child Development Biennial Meeting*, Montréal, QB.

Rabi, R. (2009, June). Influence of temporal acoustic information on short-term memory for nonwords. *Talk presented at the 2009 Annual Ontario Psychology Undergraduate Thesis Conference*, Hamilton, ON.